ASPHALTUM HAFTING AND PROJECTILE POINT DURABILITY: AN EXPERIMENTAL COMPARISON OF THREE HAFTING METHODS

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1. Introduction

Stone projectile points have long been a topic of much debate within lithic studies throughout North America. While many archaeologists (Bettinger et al. 1991; Heizer and Hester 1978; Thomas 1981, 1986; Zeanah and Elston 2001) use projectile points to construct strict chronological sequences, others (Flenniken and Raymond 1986; Flenniken and Wilke 1989; Wilke and Flenniken 1991) have argued that they represent unreliable time markers. The process of point breakage and rejuvenation could potentially alter the defining morphological characteristics and time sensitive nature of a point. However, stone projectile points continue to represent the most commonly used chronological markers in California, the Great Basin, and elsewhere due to their prevalence within the archaeological record.

Decades of archaeological research has continued to demonstrate the time sensitive nature of many projectile point types. Archaeologists have thus been able to shift their attention towards the potential influence that various factors, such as point morphology and hafting elements, may have had on point durability (Andrefskey 2009, 2010; Ellis 1997). In order to test such factors, archaeologists working in regions throughout the world have turned to experimental archaeology (Cheshier and Kelly 2006; Ellis 1997; Flenniken and Raymond 1986; Odell and Cowan 1986; Shea 1993; Shea et al. 2001; Titmus and Woods 1986; Towner and Warburton 1990; Woods 1987, 1988). Few studies, however, have considered the potential influence that different hafting methods and implements may have had on projectile point durability (cf. Titmus and Woods 1986).

The primary objective of this paper is to evaluate the relationship between asphaltum (bitumen) hafting methods and stone projectile point durability. As such, three sets of morphologically similar points were knapped, hafted using distinct hafting techniques, and shot at a composite animal target. Our results indicate that a specific asphaltum hafting method could have played a critical role in improving projectile point durability. After comparing the durability and breakage patterns associated with three distinct hafting methods, we suggest that asphaltum would have been favorably utilized under specific circumstances and may have been widely used as a hafting aid throughout ancient and historical California. In addition, we discuss some of the limitations of experimental projectile studies and make recommendations for future experimental projects.

2. Ethnohistoric Analogs

The three hafting types compared in this experiment were modeled after ethnohistorically documented techniques common to California and the Great Basin (Kroeber 1976[1925]; Latta 1949b; Powers 1873, 1877). These hafting types include sinew cross-hatched points, points hafted with a small amount of adhesive asphaltum applied to their base, and more extensive “to-the-tip” asphaltum hafted points (Figure 1; see section 3, materials and methods). Sinew wrapping of projectile points was a common hafting method in California and the Great Basin (D’Azevedo 1986; Heizer 1978) and was a documented practice utilized by the Yokuts of California’s Central Valley. Ethnographers Stephen Powers (1873, 1877), Alfred Kroeber (1976[1925]), and Frank Latta (1949) all give detailed accounts on the manufacture of projectile points and the wrapping of points with deer sinew.

The use of asphaltum as a hafting technique is also well documented in numerous ethnohistoric notes, photographs, and illustrations (Hodgson 2004; Latta 1949b; Mason 1894; Wallace 1978). Latta (1949b) provides the most comprehensive account of hunting with asphaltum based on his work with the Yowlumne Yokuts of the Kern River. As described by Latta, the Yowlumne Yokuts used asphaltum in the production of hunting arrows and various hafted knives. Latta's primary interpretation of the function of asphaltum in projectile point technology was as a waterproofing agent for sinew wrapped hunting points. It is interesting to note that Latta claimed that asphaltum was not applied to war arrows, as its application would have made the hafting too durable, facilitating the removal of arrows by wounded enemies (Latta 1949b:290). Latta's illustrations depict both the intermediate hafting method used in this project as well as the to-the-tip method (Latta 1949b:286). It is worth noting that the asphaltum to-the-tip point collected by Powers is not hafted with sinew (see below, Figure 2).

Direct analogs to our three hafting techniques can be found in specimens, photographs, and illustrations from the ethnographic accounts by Powers (1873; 1877) and Latta (1949b). Yokuts point specimens collected by Powers from the San Joaquin Valley in 1875 are curated at the Smithsonian Institution (see Smithsonian Index for Artifact E19709-0), with the asphaltum to-the-tip point illustrated in various publications (see Hodgson 2004; King 1978; Mason 1894; Wallace 1978). All of these examples were referenced while designing and implementing our experimental procedures.

3. Materials and Methods

As discussed by Outram (2008:3-4), it is important for projects in experimental archaeology to closely simulate real world conditions in order to minimize the degree to which results could be considered inauthentic. On the other hand, experimental projects face real constraints in terms of logistics, ethics and time. The need for scientific experiments to be repeatable and conducted in controlled environments puts further strains on the ability of experimenters to replicate real world conditions. Projects in experimental archaeology, therefore, must walk a fine line between authenticity and achievability. In this project we made every effort to maintain test conditions that were both scientifically sound and as authentic as possible. The following section will detail the experimental process and discuss the decisions we made in attempting to maintain realistic testing conditions.

The points used in this project were knapped by the authors using high quality obsidian from Mexico and Oregon. We manufactured points by pressure flaking using a copper tipped pressure flaker and a synthetic abrader. Our objective was to create triangular points with a length of just over 2 cm, and a basal width of about 1.5 cm. As seen in Table 1, our resulting points matched these requirements fairly closely. Any points with obvious defects or blemishes were discarded and replaced. The triangular shape of the points are not meant to be exact replicas of any particular point type, but rather represent a generic and average sized point similar to many that were used throughout California and the Great Basin after the adoption of the bow and arrow. The closest archaeological analogue to our points would be the Cottonwood type (Justice 2002; Lanning 1963; Riddell 1951; Thomas 1981), which is common in archaeological contexts throughout California and the Great Basin. Thomas (1981:16) has described the Cottonwood type as "small, unnotched, thin, triangular projectile points" with a basal width/maximum width ratio greater than .9; a definition which would match our points. After hafting, some points were moderately retouched in order to ensure sharpness. Although some point lengths may have been slightly altered by this process, we do not believe such modifications would have had a significant effect on our results.

We decided to use a total of 60 points for this project, with 20 points representing each sample test group. Although using a small number of points in each sample group decreased the likelihood of obtaining statistically significant differences, it was a practical necessity. Even with only 60 points, the shooting section of this experiment took a full three days, including field preparation and setup. Preparing for a longer experiment would not have been logistically feasible. Individual point numbers were applied and recorded during the hafting process. During the initial shooting phase, 5 of the intermediate asphaltum points were lost in the hay backing of our target. Subsequently, all sample groups were limited to 15 points each.

All of our points were hafted to 7.5 cm long hardwood foreshafts measuring .31 cm (5/16ths of an inch) in diameter. The proximal ends of each foreshaft were tapered to facilitate attachment to the main arrow shaft. Each foreshaft was also hand-carved with a notch to match it with a specific point. During experimentation, some foreshafts broke and were reshaped in the field with a pocket knife. In a few rare cases, points were separated from their foreshafts without breaking and were re-hafted in the field. In some cases such repair resulted in a slight reduction in foreshaft length, but we do not believe these changes had a significant impact on the results of our experiment.

Although a wide variety of hafting methods and materials could be imagined for Cottonwood points, practical considerations forced us to limit our study to three experimental groups. As previously discussed, these included sinew hafted points, intermediate asphaltum hafted points, and asphaltum to-the-tip points. Sinew hafted points were wrapped in a standard cross-hatched, X-shaped pattern (Figure 1). This hafting type matches that used for Desert-Side-Notched points and is documented as being used throughout California and the Great Basin by a considerable number of ethnohistoric and archaeological studies (D'Azevedo 1986; Fenenga and Riddell 1949; Justice 2002; King 1978:68). The sinew used in this project came from deer (*Odocoileus virginianus*) backstraps that were soaked in water, pounded with a stone *mano*, and chewed in order to produce the desired plasticity and glue-like bond for hafting purposes. The sinew was then wrapped across the edges of each point and around the base. Sinew hafted points had sections of their edges dulled so as not to cut into the sinew. Approximately 30 cm of sinew was used on each sinew hafted point. Regardless of hafting technique, all foreshafts also had an additional 15-20 cm of sinew wrapped just below the base of the point in order to prevent the foreshaft from splitting on impact.

Two types of asphaltum hafted points were used in this project. The first type, intermediate points, were prepared by applying a dab of heated asphaltum to the notch of the foreshaft (Figure 1). The point was then fitted into the notch and the asphaltum was allowed to harden, forming a glue-like bond between the arrow and the foreshaft. The second type, to-the-tip points (Figure 1), were prepared in a similar fashion, but had extra asphaltum applied to the midsection and tip of the point using a pointed wooden dowel. The goal of this process was to leave only the edges and very tip of the point uncovered by asphaltum. As mentioned previously, asphaltum was used to haft points by groups throughout California, but was especially common among the Central Valley Yokuts (Wallace 1978). The to-the-tip points have a specific historical analogue in a Yokuts point collected in 1875, and currently curated at the Smithsonian Institution (Wallace 1978:452; See Figure 2).

The asphaltum used in this project was collected from the La Brea tar seeps in Los Angeles County. Several steps were taken in order to prepare the asphaltum for use in hafting points. First, we boiled the asphaltum for 10 to 15 minutes in order to remove any water in the tar. Next, we added crushed agave (*Agave deserti*) charcoal to the asphaltum to serve as a temper. The ratio of agave charcoal to asphaltum prior to mixing was approximately 1:1 by volume, but the exact amount was difficult to measure during field preparation. We found that the best way to prepare the asphaltum was to continuously add charcoal until the mixture reached the desired point of thickness. During the hafting process, the asphaltum mixture was kept warm using a propane camping stove.

Points are only one part of a larger weapons system. Indeed, despite their relatively small archaeological signature, shafts and bows represent a much greater degree of labor investment than do flaked points. In this project, we used 85 cm long aluminum arrow shafts with plastic fletching. Foreshafts were hafted to these aluminum shafts by dabbing a small amount of asphaltum to the arrow shaft prior to inserting the foreshaft, producing a snug and stable fit between the foreshaft and arrow. The use of aluminum arrows, although clearly not historically accurate, eliminated any possible problems involving arrow shaft breakage and maintenance. Additionally, the aluminum arrows and plastic fletching provided a greater degree of flight consistency for each shot; minimizing the variables involved in point breakage. Considering that our project was focused on variables involving point breakage and hafting, we do not believe that the use of aluminum arrows adversely affected our results. On the contrary, we feel that this delivery system strengthened our methodology by eliminating possible problems and reducing extraneous variables that could influence point breakage.

An important consideration for any study of point breakage patterns is the target at which points are shot. Many studies (Cheshier and Kelly 2006; Flenniken and Raymond 1986; Odell and Cowan 1986; Shea et al. 2001) use whole animal carcasses in order to closely replicate hunting situations. Although animal carcasses do represent the most ethically available analog to real world conditions, they are far from perfect replicas of moving, bleeding, animals. Furthermore, there are numerous procedural problems involved in field experimentation with animal carcasses. For one, the various parts of the body do not have consistent amounts of bone, which is the primary culprit in point breakage. Where the arrows hit in the carcass, therefore, can alter the results of breakage studies. The need to field dress the animal after every shot to inspect and retrieve points also causes considerable problems. Such operations take time and alter the condition of the animal, decreasing the consistency achievable between each shot.

Instead of an animal carcass, we decided to construct a composite animal target (Figure 3). The primary components of this target consisted of a pig (*Sus scrofa*) skin covering a large side of pig ribs. These components created a simulated animal target approximately 50 cm long by 20 cm tall. This target was then backed against eight .95 cm (3/8ths of an inch) thick foam pads, which were mounted on a bale of hay for support. The combined composite target was held together by two .64 cm (1/4th inch) rebar rods. This composite target system has several advantages over an animal carcass. First of all, the target could be easily deconstructed, allowing for the rapid collection and inspection of shot points. This both saves precious experiment time and allows for the quick identification of causes of point breakage in the field. Secondly, due to its composite nature, damaged portions of the target are easily replaceable, thus maintaining maximum consistency between each shot. We found that repeated damage from shots, as well as dry and hot weather conditions, considerably changed the condition of the target over time. Because of this, we replaced both the skin and ribs of the target between each sample test group. Finally, the composite target has the advantage of being more logistically feasible than an animal carcass. Although this set up does not approximate a real life target as closely as a whole carcass, we believe that it is in many ways superior. As bones are the primary cause of point breakage, the replacement of the animal's internal organs with a foam backing is unlikely to greatly decrease incidents of breakage or change breakage patterns.

All of the points used in this project were shot by Mikael Fauvelle or Sean Brown, at a distance of 5 meters from the target. Although this distance is shorter than what would be expected for real life situations, it is greater than that used in comparable experiments (Cheshier and Kelly 2006; Waguespack et al. 2009). The arrows were shot using a fiberglass bow with a pull of about 30 pounds, which is comparable to that of many indigenous bows used in pre-contact North America (Hamilton 1972; Pope 1923). Every point was shot until it broke, with repairs to the foreshaft conducted as necessary. Once a point broke, the cause of breakage was noted along with the number of shots and the location of impact. Most shots hit the animal component of the target, but missed shots which hit the foam were recorded as well. No points or foreshafts were visibly affected by impacts with foam. As previously mentioned, the animal portions of the composite target were replaced between each of the three test groups in order to ensure that the meat had similar properties across all shots.

4. Results and Discussion

The number of shots each point went through before breaking is displayed in Table 2, together with the type of break that affected each point. As noted in previous studies (Cheshier and Kelly 2006; Shea 1993; Titmus and Woods 1986; Woods 1988), most projectile points do not last very long. In total, 20 out of 45 points broke on the first shot, an additional 9 broke on the second shot and the remainder lasted for three or more shots. Points that survived the first few shots seemed to have a tendency to last over a few additional uses before breaking. Generally, our results compare well with those reported by Cheshier and Kelly (2006); the average shots for all of our points was 2.6, compared to 2.2 in their experiment. One noticeable difference concerns the location of breakage, with tip fractures being the most common in our experiment while ear fractures predominated among the side notched points used by Cheshire and Kelly (2006:358-359). This difference emphasizes the importance of point morphology and hafting techniques in shaping breakage patterns; an issue that will be taken up later in this discussion.

As predicted, the average number of shots needed to break a point varied across the three sample groups. Points hafted with asphaltum to the tip lasted the longest, with an average of 3.3 shots before breaking (30% chance of breakage per shot). Intermediate points hafted with a dab of asphaltum at the base lasted an average of 2.5 shots (40% change of breakage per shot). Those hafted with sinew were the most likely to break on impact, lasting an average of 1.8 shots (56% chance of breakage per shot). This pattern closely matched our expectations, with a clear trend of increased durability moving across the three test groups from sinew points to intermediate points and finally to the points with asphaltum running all the way to the tip.

Our original hypothesis was that the asphaltum hafted points would be more durable than those hafted with sinew. In order to check whether one sample group is more durable than another, a one tailed t-test is appropriate. Using such a t-test, the difference in means between the sinew hafted and to-the-tip asphaltum points is statistically significant ($p=.026$). Even using a two tailed t-test (under the assumption that either group may have been more durable) the results remain significant at the .1 level (See Table 3). The differences between the intermediate points and the other two hafting techniques are not statistically significant, but relatively low p values (in both cases $<.2$) are suggestive of correlation discussed above across the three groups. Boxplots displaying the differences between the three sample groups can be seen in Figure 4. One possible outlier, point 47, was hafted using the cross-hatched method and was shot six times without breaking. Removing this outlier and recalculating the t-test using replacement of means yields a p value of .007, returning a significant difference at the .01 level. In addition to t-tests, we also conducted three different tests that do not make an assumption of normal distributions. A Kruskal-Wallis test comparing all three samples returned a non-significant result with a p of .277. Three pairwise Mann-Whitney U tests also returned non-significant results (See Table 3). A two-tailed pairwise bootstrapping comparison of means using 25,000 iterations, however, did return a significant difference between the cross-hatched and to-the-tip sample groups (p=.049). Points hafted with asphaltum to-the-tip following the ethnohistorically documented Central Valley Yokuts (Wallace 1978:452), therefore, can be said to show a small but significant increase in durability over those hafted following a standard cross-hatched sinew method.

Breakage patterns also varied considerably between groups. As seen in Table 2, to-the-tip asphaltum hafted points generally suffered tip fractures, while sinew hafted points were far more likely to break at the midsection of the point. This difference is difficult to quantify statistically, but can be indicated by the fact that after breaking, 33% of asphaltum to-the-tip points retained 90% of their original length, compared to only 13% for sinew hafted points. This is important as points retaining 90% or more of their original length are far more likely to be candidates for rejuvenation through re-knapping (Table 4). This difference also makes physical sense when one considers the construction of the various hafting types. Sinew hafted points face an extra point of resistance at the point where the sinew connects with the edge of the point (Figure 5). Therefore, it should not be surprising that many sinew hafted points broke exactly at the sinew cross-section (Figure 5). Points hafted with asphaltum to their tips, on the other hand, would be expected to obtain extra durability from their asphaltum coating, warding off midsection breaks. In addition to being more durable, points hafted with asphaltum are thus also more likely to be re-used even after breakage.

For a hunter equipped with stone tools, the degree to which a point can be rejuvenated is likely to be equally if not more important than the point's durability. Previous studies suggest that hunters in early California and the Great Basin often re-worked spent points multiple times before finally discarding them, greatly expanding the use-life of their tools (Flenniken and Raymond 1986; Flenniken and Wilke 1989; Towner and Warburton 1990). Only certain kinds of breaks, however, allow the knapper to re-work the projectile into a useable point. Midsection breaks, for example, are unlikely to leave a large enough section of the point intact to be re-usable through rejuvenation. Tip fractures, on the other hand, can often be repaired with minimal effort. The tendency of fully asphaltum hafted points to break at the tip, therefore, would be an advantageous attribute for any early hunters interested in curating their lithic materials. Combined with their slightly higher durability on impact, these features could have made the asphaltum hafting technique very useful in areas where high quality lithic material such as obsidian was acquired through external trade.

As generally conceived, the primary function of a stone projectile point is to create a puncture in an animal's skin through which the rest of the projectile can pass. Carefully prepared asphaltum points, with only the center of the projectile covered leaving the point and cutting edges exposed, should lose no functionality in this regard when compared to other hafting methods. Sometimes, however, ancient hunters may have been interested in attributes other than durability. Ethnohistoric accounts indicate that fragmented stone points continue to penetrate the wounded animal as it attempts to escape (Ellis 1997). As such, points that break within the target might be more effective at causing internal bleeding, thus increasing the likelihood of killing the animal. Sinew hafting has the benefit of being easily prepared on the move and in the field; a key advantage over asphaltum hafted points which would require heat from a fire in order to melt and apply the tar. Sinew hafting would also avoid the risk of melting during high summer temperatures, which the Central Valley Yokuts may have mitigated by introducing various additives to the asphaltum (Sutton 1990). Although asphaltum hafting may have increased the durability and re-use potential of projectile points, it is therefore unlikely that it would have been a preferred hafting method in all situations. Rather, we can expect that asphaultum hafting would only have been used under certain conditions, such as cases where there was ample time to prepare points, and where asphaltum was seen as a more readily available resource than obsidian or chert. In areas of California and the Great Basin where asphaltum was not readily available other materials such as pine pitch, creosote lac scale insect resin, and glue from bighorn sheep horns and hides could have been utilized for hafting purposes (Sutton 1990).

The form of any tool should logically follow its function. As such, some archaeologists have wondered why the relatively common Cottonwood point would lack notches; especially if it was intended to be hafted with cross-hatched sinew. On one extreme, this has led to the suggestion that many Cottonwood points were in fact Desert-Side-Notch pre-forms (Morris 1981; Sutton and Arkush 2002). In this paper we have discussed three effective ways of hafting triangular points, none of which are likely to have been improved through side-notching. In addition to sinew hafted points, many of the Cottonwoods found in Southern California may have been intended for asphaltum hafting. Such a scenario would have been increasingly likely in areas such as the Central Valley and the Los Angeles basin, where asphaltum would have been readily available.

Some issues regarding the archaeological signature of asphaltum hafting are also worthy of discussion. While there are a number of ethnohistoric examples from California's Central

Valley of Cottonwood points hafted with asphaltum (Kroeber 1976[1925]; Latta 1949b; Powers 1873, 1877), excavated Cottonwood points from archaeological contexts showing evidence of asphaltum hafting are exceedingly rare. On the other hand, the earlier leaf-shaped points common in southern California immediately after the introduction of the bow and arrow do regularly display evidence of asphaltum hafting (Glassow et al. 2007:208). How might we explain this pattern? One possibility involves the changing value of asphaltum over the course of the second half of the first millennium C.E.. As discussed by several scholars (Arnold 1993; Fauvelle 2011), trade in asphaltum became a critical component of political-economic systems in the Santa Barbara Channel region after the development of the asphaltum-covered plank canoe around 1,500 B.P.. Although asphaltum sources exist near modern day Santa Barbara, it was also a major trade item supplied by the Yokuts of the central valley in exchange for coastal shell beads. As coastal demand for asphaltum increased, it is possible that the use of asphaltum for hafting arrows declined. The ideological value of asphaltum may also have shifted due to its growing association with the cosmologically significant Chumash cult of the canoe. It is possible that the asphaltum hafting of Cottonwood points may have seen a renaissance during ethnohistoric times following the decline of the Chumash canoeing way of life and the collapse of pre-contact trade systems.

Although statistically significant, the difference in durability provided by the to-the-tip asphaltum hafting method is relatively small. In times of resource stress the added ability to curate obsidian through asphaltum hafting may have provided a critical advantage, but in general, both asphaltum and sinew hafting are likely to have been widely used. We would emphasize, therefore, that the point of this paper is not to show that asphaltum hafting is a better or more advantageous method, but rather to stress the fact that hafting techniques in Southern

California were likely to be contingent on multiple factors, including both resource availability and intended use. Furthermore, we suggest that the projectile hafting potential of asphaltum adds to the already long list of industries associated with this key resource (Arnold 1993; Fauvelle 2011; Hudson et al. 1986; Latta 1949a, 1949b). Considering the uneven distribution of asphaltum sources across the landscape, future studies are needed to better understand the role asphaltum played within early Southern Californian economic systems.

5. Conclusions

This paper has demonstrated that the choice of a particular hafting technique can have a significant influence on the durability and potential breakage patterns associated with stone projectiles. Working from ethnohistoric descriptions of asphaltum hafted points used by the Yokuts of the California's Central Valley (Latta 1949b; Wallace 1978), we prepared three different sample groups designed to test the relationship between point durability and asphaltum hafting methods. The results displayed a statistically significant increase in durability among those points hafted with the to-the-tip asphaltum technique compared to those using a more stereotypical sinew cross-hatched method. Such results highlight the potential significance of differential hafting methods that may have been used in pre-contact California and emphasize that hafting designs would have been influenced by a wide range of factors including resource availability, available preparation time, and the perceived importance of point durability.

We would also like to stress some of the implications of the methods which we used in carrying out this experiment. One of the biggest problems encountered in projectile point experiments involves the collection of a sufficient amount of data to produce robust and significant results. Experimental projects involve real constraints on the availability of time and materials which restrict the number of points, and thus the amount of data, that can be included in experimental designs. To mitigate such factors, we incorporated a number of time-saving strategies into our methods, including the use of aluminum arrow shafts and the construction of a composite animal target. We suggest that such elements helped to streamline the experimental process, without significantly compromising the need to maintain realistic experimental conditions; a conclusion we believe is supported by the fact that our results are closely comparable to those produced by previous experiments (Cheshier and Kelly 2006; Titmus and Woods 1986). We hope future experimental projects will continue to innovate with methodological designs in order to increase the statistical strength of data collected from projectile point experiments.

As previously mentioned, the use of asphaltum in a number of pre-contact Californian industries is well documented (Arnold 1993; Fauvelle 2011; Hudson et al. 1986; Latta 1949a, 1949b). Other than its use as a water-proofing agent, asphaltum's role in Southern Californian arrow hafting technology has remained underexamined. Hafting and fletching would have represented considerably greater time investments than actual knapping. However, these activities are poorly represented in the archaeological record. We suggest that the widespread availability of asphaltum in Southern California, together with the relative commonness of the Cottonwood point type, indicate that asphaltum hafting may have been a fairly regular practice in the region. This would add to the wide range of uses for asphaltum by early Californians and emphasize this key resources importance.

Asphaltum hafted points following the Yokuts inspired to-the-tip method displayed significantly greater durability in this experiment than points hafted with a traditional sinew method. Durability, however, may not have been the primary goal of all pre-contact knappers.

Comparing our results with those of Cheshier and Kelly (2006), side notching does not appear to have substantially increased the effectiveness of sinew hafting; a prediction which is in need of confirmation through further experimentation. Such observations raise the question of whether side notches are designed to increase the likelihood of breakage patterns desired by the knapper (Cheshier and Kelly 2006:362). This is especially likely in the case of basal notches, which do not serve any clear hafting related function. While asphaltum hafting might have been a useful strategy in times when obsidian was in short supply, it may not always have produced the outcome desired by pre-contact hunters. Hopefully future experimental work will serve to address some of these questions and further expand our understanding of ancient projectile systems.

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References

Andrefsky, W., 2009. The Analysis of Stone Tool Procurement, Production, and Maintenance. Journal of Archaeological Research. 17, 65-103.

Andrefsky, W., 2010. Human Land-use Strategies and Projectile Point Damage, Resharpening, and Discard Patterns. Human Evolution. 25, 13-30.

Arnold, J.E., 1993. Chumash Technology: New Discoveries of uses of Imported Redwood and Asphaltum on the Channel Islands, Proceedings of the Society for California Archaeology 6, 277-285.

Bettinger, R.L., O'Connell, J.F., Thomas, D.H., 1991. Projectile Points as Time Markers in the Great Basin. American Anthropologist. 93, 166-172.

Cheshier, J., Kelly, R. L., 2006. Projectile Point Shape and Durability: The Effect of Thickness: Length. American Antiquity. 71, 353-363.

D'Azevedo, W.L., 1986. Handbook of North American Indians: Great Basin, Volume 11. Smithsonian Institution Press, Washington D.C..

Ellis, C.J., 1997. Factors Influencing the Use of Stone Projectile Tips: An Ethnographic Perspective, in: Knecht H. (Eds.) Projectile Technology, Plenum Press, New York, pp. 37-74.

Fauvelle, M., 2011. Mobile Mounds: Asymmetrical Exchange and the Role of the Tomol in the Development of Chumash Complexity. California Archaeology. 3, 141-158.

Fenenga, F., Riddell, F.A., 1949. Excavations of Tommy Tucker Cave, Lassen County, California. American Antiquity. 14, 204-214.

Flenniken, J.J., Raymond, A. W., 1986. Morphological projectile point typology: replication experimentation and technological analysis. American Antiquity. 51, 603-614.

Flenniken, J.J., Wilke, P.J., 1989. Typology, Technology, and Chronology of Great Basin Dart Forms. American Anthropologist. 91,149-158.

Glassow, M., Gamble, L., Perry, J., Russell, G., 2007. Prehistory of the Northern California Bight and the Adjacent Transverse Ranges, in: Jones, T.L., Klar, K.A. (Eds.), California Prehistory: Colonization, Culture, and Complexity, AltaMira Press, Lanham, pp. 191-214.

Hamilton, T., 1972. Native American Bows. Missouri Archaeological Society, Columbia.

Heizer, R.F., 1978. Handbook of the North American Indians: Volume 8, California, Smithsonian Institution, Washington.

Heizer, R.F., Hester, T.R., 1978. Great Basin Projectile Points: Forms and Chronology, Ballena Press, Socorro.

Hodgon, S.F., 2004, California Indians, Artisan of Oil, California
Department of Conservation, Division of Oil, Gas, and Geothermal Resources, Sacramento.

Hudson, T., Blackburn, T. C., Lee, G., 1986. The material culture of the Chumash interaction sphere. Ballena Press, Socorro.

Justice, N., 2002. Stone Age Spears and Arrow Points of California and the Great Basin, Indiana University Press, Bloomingten.

King, C., 1978. Protohistoric and Historic Archaeology, in: Heizer, R.F., (Ed.), Handbook of the North American Indians: Volume 8, California. Smithsonian Institution Press, Washington D.C., pp. 58-68.

Kroeber, A.L., 1976[1925]. Handbook of the Indians of California, General Publishing Company, Ontario.

Lanning, E.P., 1963. Archaeology of the Rose Spring Site INY-372. University of California Publications in American Archaeology and Ethnology, Berkeley.

Latta, F.F., 1949a. Black Gold in the Joaquin, The Caxton Printers, Ltd., Caldwell.

Latta, F.F., 1949b. Handbook of Yokuts Indians, Bear State Books, Santa Cruz.

Mason, O.T., 1894, North American Bows, Arrows, and Quivers. The Smithsonian Report for 1893, Government Printing Office, Washington, D.C..

Morris, A.J., 1981. A Report on the Archaeological Survey of 10,000 Hectares of Range Seeding Projects, Harney County, Oregon, Bureau of Land Management, Burns District.

Odell, G.H., Cowan, F., 1986. Experiments with spears and arrows on animal targets. Journal of Field Archaeology, 13. 195-212.

Outram, A. K., 2008. Introduction to experimental archaeology. World Archaeology. 40,1-6.

Pope, S.T., 1923. A Study of Bows and Arrows, University of California Publications in American Archaeology and Ethnology, Volume 13, Number 9, University of California Press, Berkeley.

Powers, S., 1873. The California Indians. The Overland Monthly and Out West Magazine, San Francisco.

Powers, S., 1877. Tribes of California. Contribution to North American Ethnology, Vol. 3, Government Printing Office, Washington, D.C..

Riddell, H. S., 1951. The Archaeology of a Paiute Village Site in Owens Valley, University of California Archaeological Survey Reports, Berkeley.

Shea, J.J., 1993. Lithic use-wear evidence for hunting in the Levantine Middle Paleolithic. Traces et Fonction: Les Gestes Retrouves, 50, 21-30.

Shea, J., Davis, Z., Brown, K., 2001. Experimental tests of Middle Palaeolithic spear points using a calibrated crossbow, Journal of Archaeological Science 28, 807-816.

Sutton, M.Q., 1990. Notes on Creosote Lac Scale Insect Resin as a Mastic and Sealant in the Southwestern Great Basin. Journal of California and Great Basin Anthropology. 12, 262-268.

Sutton, M.Q., Arkush, B.S., 2002. Archaeological Laboratory Methods: An Introduction, Hunt Publishing Company, Kendall.

Thomas, D. H., 1981. How to classify the projectile points from Monitor Valley, Nevada. Journal of California and Great Basin Anthropology. 3, 7-43.

Thomas, D.H., 1986. Points on Points: A Reply to Flenniken and Raymond. American Antiquity. 51, 619-627.

Titmus, G.L., Woods, J.C., 1986. An experimental study of projectile point fracture patterns. Journal of California and Great Basin Anthropology. 8, 37-49.

Towner, R. H., Warburton, M., 1990. Projectile point rejuvenation: a technological analysis. Journal of Field Archaeology. 17, 311-321.

Waguespack, N.M., Surovell, T.A., Denoyer, A., Dallow, A., Savage, A., Hyneman, J., Tapster, D., 2009. Making a point: wood-versus stone-tipped projectiles. Antiquity. 83, 786-800.

Wallace, W.J., 1978. Southern Valley Yokuts. In: Heizer, R.F., (Ed.), Handbook of the North American Indians: Volume 8, California, Smithsonian Institution Press, Washington D.C..

Wilke, P.J., Flenniken, J.F., 1991. Missing the Point: Rebuttal to Bettinger, O'Connell, and Thomas. American Anthropologist. 93, 172-173.

Woods, J.C., 1987. Manufacturing and Use Damage on Pressure-Flaked Stone Tools. Unpublished Master's thesis, Idaho State University, Pocatello.

Woods, J.C., 1988. Projectile Point Fracture Patterns and Inferences About Tool Function. Idaho Archaeologist. 11, 3-7.

Zeanah, D.W., Elston, R.G., 2001. Testing a Simple Hypothesis Concerning the Resilience of Dart Point Styles to Hafting Element Repair. Journal of California and Great Basin Anthropology. 23, 93-124.

Figure 1. Examples of spent points depicting, from left to right, sinew hafted, intermediate, and to-the-tip points. The foreshaft of point 37 (to-the-tip), was re-worked in the field, making it shorter than the other points depicted her.

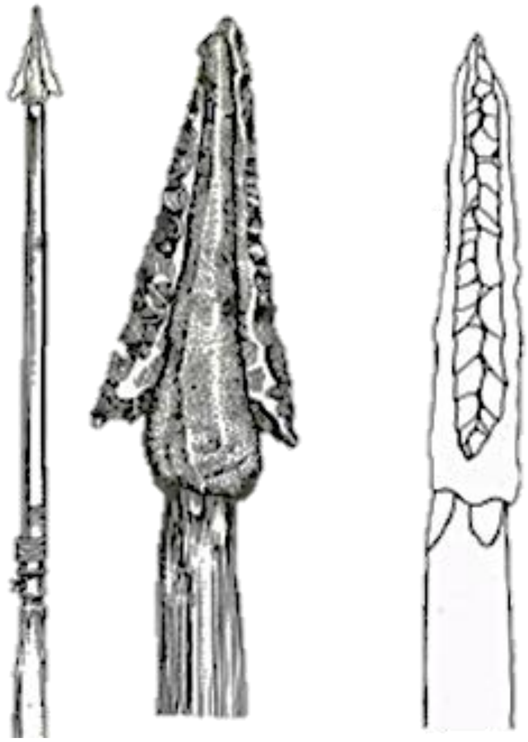

Figure 2. Example of a Yokuts style asphaltum hafted point. Permission to reprint provided by Smithsonian Institution.

Figure 3. Composite animal target consisting of a pig skin covering a large rack of ribs, backed against eight 0.95 cm thick camping pads. The entire assemblage was attached to a bale of hay with two rebar rods. After each shot the target could be quickly disassembled to retrieve points and assess the cause of breakage, as seen in the second image where a spent point is lodged in bone.

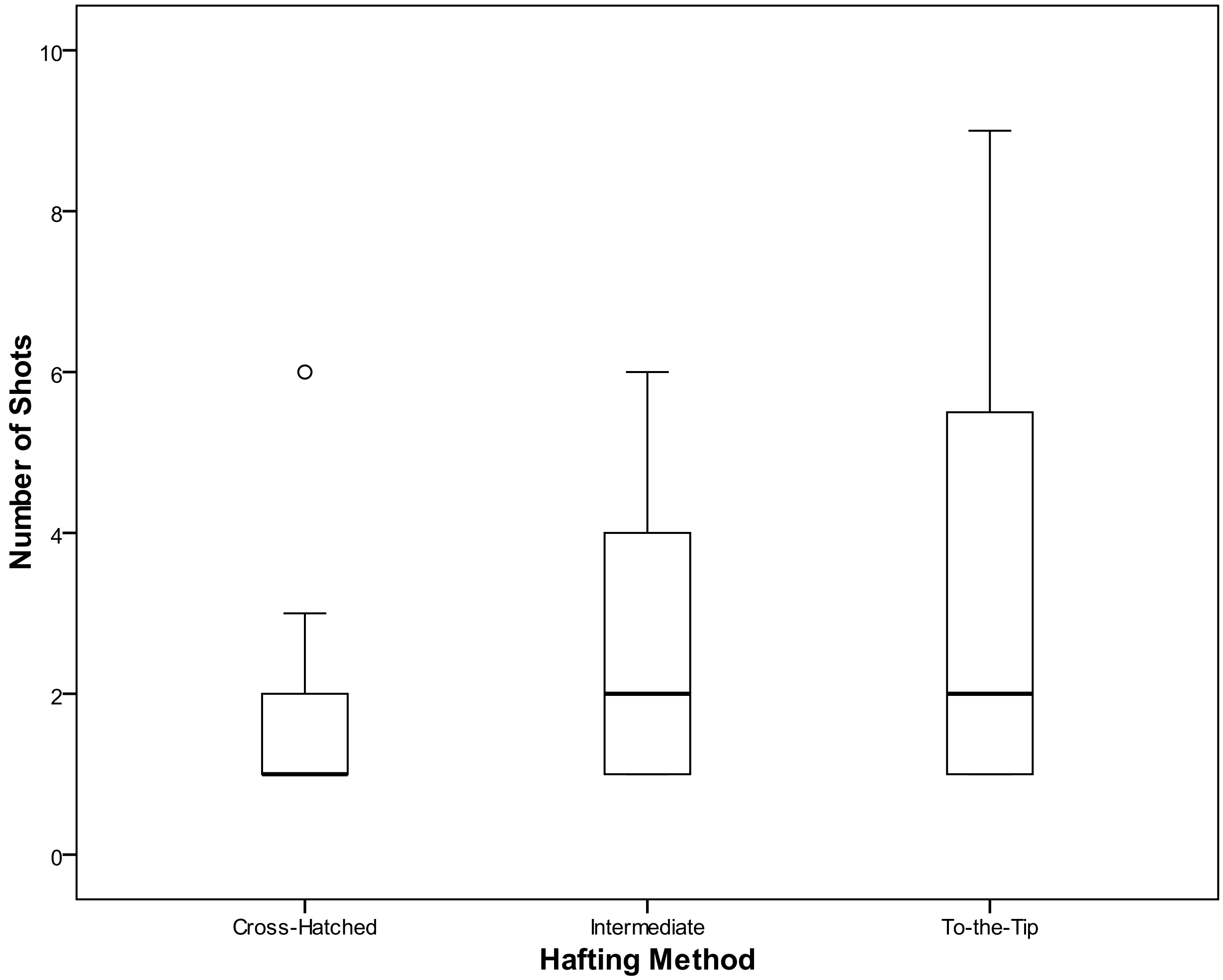

Figure 4. Box and whisker plots displaying the differences in numbers of shots between each of the three hafting groups. This graph depicts point 47 as an outlier.

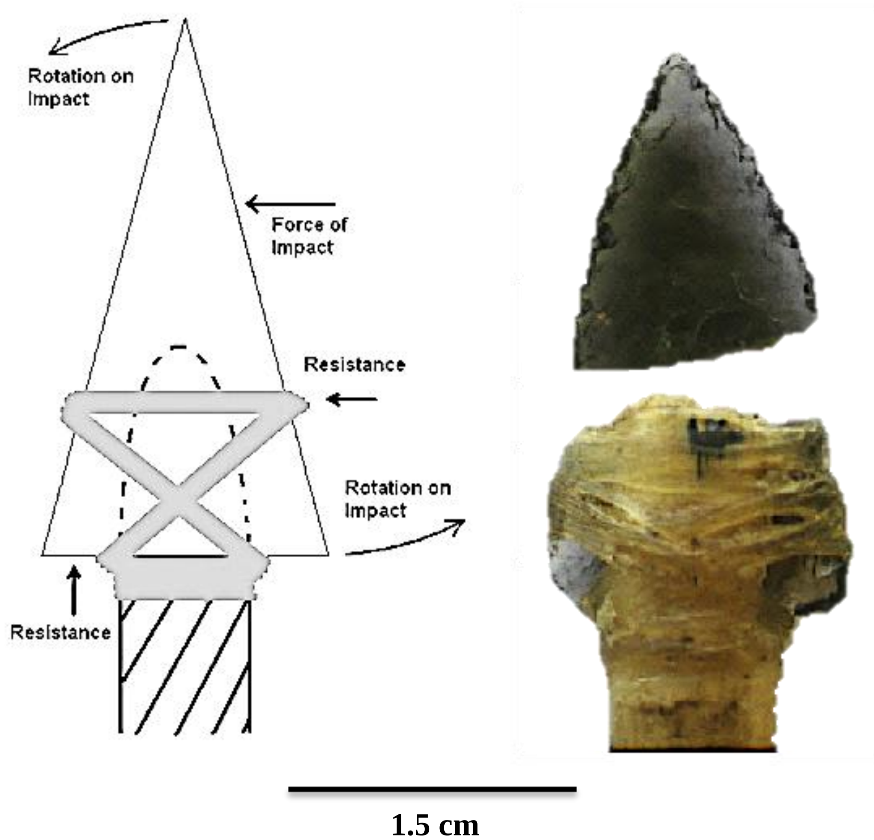

Figure 5. Diagram representing the forces involved in an impact fracture on a sinew hafted point. Note the tendency to break at or just above sinew cross-hatches, as evident in the picture to the right.

Table 1. Metric measurements of points

Point #	Hafting Method	Length (cm)	Thickness (cm)	Basal Width (cm)	L:Bw	Weight (g)
1	intermediate	2.15	0.36	1.68	1.28	1
2	intermediate	2.32	0.28	1.54	1.51	0.7
3	intermediate	2.28	0.3	1.51	1.51	0.9
4	intermediate	2.42	0.36	1.81	1.34	1
5	intermediate	2.24	0.28	1.57	1.43	0.8
6	intermediate	2.01	0.31	1.47	1.37	0.7
7	intermediate	2.49	0.31	1.66	1.5	1.1
8	intermediate	2.13	0.34	1.38	1.54	0.8
9	intermediate	2.38	0.34	1.58	1.51	0.9
10	intermediate	2.62	0.37	1.76	1.49	1.2
11	intermediate	2.08	0.29	1.47	1.42	0.7
12	intermediate	2.12	0.3	1.55	1.37	0.8
13	intermediate	2.45	0.3	1.47	1.67	1
14	intermediate	2.33	0.34	1.46	1.59	0.9
15	intermediate	2.08	0.18	1.44	1.44	0.5
16	intermediate	2.26	0.24	1.45	1.56	0.7
17	intermediate	2.07	0.31	1.56	1.33	0.6
18	intermediate	2.3	0.31	1.43	1.6	0.7
19	intermediate	2.41	0.36	1.55	1.55	1
20	intermediate	2.31	0.31	1.74	1.33	0.9
21	tip	2.47	0.33	1.63	1.51	1.1
22	tip	2.32	0.3	1.33	1.74	0.8
23	tip	2.48	0.36	1.87	1.33	1.1
24	tip	2.61	0.31	1.64	1.59	1.1
25	tip	2.31	0.27	1.58	1.46	0.8
26	tip	2.11	0.24	1.53	1.38	0.6
27	tip	2.46	0.28	1.41	1.74	0.8
28	tip	2.58	0.29	1.55	1.66	1
29	tip	2.27	0.28	1.57	1.44	0.7
30	tip	2.39	0.3	1.49	1.6	1
31	tip	2.52	0.25	1.79	1.4	1
32	tip	2.36	0.29	1.71	1.38	1.1
33	tip	2.44	0.2	1.57	1.55	0.6
34	tip	2.21	0.25	1.52	1.45	0.8
35	tip	2.18	0.36	1.66	1.31	1
36	tip	2.37	0.29	1.46	1.62	0.8
37	tip	2.43	0.34	1.56	1.55	1.1
38	tip	2.16	0.26	1.36	1.58	0.7
39	tip	2.54	0.38	1.37	1.85	1
40	tip	2.39	0.3	1.47	1.62	0.9

41	cross-hatched	2.52	0.36	1.61	1.56	1.1
42	cross-hatched	2.43	0.34	1.54	1.57	0.9
43	cross-hatched	2.3	0.34	1.62	1.42	0.9
44	cross-hatched	2.59	0.36	1.76	1.47	1.2
45	cross-hatched	2.56	0.39	1.74	1.47	1.2
46	cross-hatched	2.03	0.24	1.52	1.34	0.6
47	cross-hatched	2.06	0.39	1.6	1.29	0.7
48	cross-hatched	2.17	0.38	1.55	1.4	0.9
49	cross-hatched	2.28	0.29	1.47	1.55	0.9
50	cross-hatched	2.33	0.25	1.56	1.49	0.8
51	cross-hatched	2.5	0.38	1.73	1.44	1.2
52	cross-hatched	2.5	0.39	1.43	1.74	0.9
53	cross-hatched	2.51	0.25	1.66	1.51	0.9
54	cross-hatched	2.59	0.34	1.78	1.45	1.4
55	cross-hatched	2.15	0.32	1.49	1.44	0.8
56	cross-hatched	2.48	0.34	1.52	1.63	0.8
57	cross-hatched	2.5	0.29	1.44	1.73	0.8
58	cross-hatched	2.48	0.32	1.39	1.78	0.8
59	cross-hatched	2.33	0.35	1.61	1.45	1
60	cross-hatched	2.18	0.25	1.47	1.48	0.7

Table 2. Comparison of Point Durability and Breakage

Point Number	Hafting Method	Shots	Break Type	Point Number	Hafting Method	Shots	Break Type	Point Number	Hafting Method	Shots	Break Type
31	cross-hatched	2	mid-section	1	intermediate	1	tip	21	To-the-tip	1	tip
45	cross-hatched	2	tip	2	intermediate	1	midsection	22	To-the-tip	1	tip
46	cross-hatched	1	mid-section	4	intermediate	6	midsection	23	To-the-tip	1	mid-section and tip
47	cross-hatched	6	tip	5	intermediate	2	side to base	25	To-the-tip	1	tip
48	cross-hatched	1	tip	8	intermediate	5	tip	26	To-the-tip	1	tip
49	cross-hatched	1	tip	9	intermediate	2	tip	27	To-the-tip	3	mid-section
51	cross-hatched	1	tip	10	intermediate	1	tip	28	To-the-tip	6	tip
52	cross-hatched	2	tip	11	intermediate	3	tip	29	To-the-tip	9	tip
54	cross-hatched	1	mid-section	13	intermediate	4	tip	30	To-the-tip	2	tip
55	cross-hatched	2	tip	14	intermediate	2	tip	32	To-the-tip	6	tip
56	cross-hatched	1	mid-section	15	intermediate	1	midsection	34	To-the-tip	2	tip
57	cross-hatched	1	mid-section	16	intermediate	4	midsection	36	To-the-tip	1	tip
58	cross-hatched	1	mid-section	17	intermediate	4	tip	37	To-the-tip	5	tip
59	cross-hatched	3	tip	18	intermediate	1	tip	38	To-the-tip	5	tip
60	cross-hatched	2	tip	19	intermediate	1	tip	40	To-the-tip	6	tip
Mean # of hits		1.8				2.5				3.3	
Standard Deviation		1.74				2.84				6.8	

Table 3. Statistical Analysis

Comparison	P(T<=t) one-tail		P(T<=t) two-tail		Kruskal-Wallis	Mann-Whitney U test	Bootstrapping	
Sinew to to-the-tip	0.026	*	0.052	**	0.277	0.152	0.049	*
Sinew to intermediate	0.098	**	0.195		0.277	0.504	0.226	
Intermediate to to-the-tip	0.164		0.327		0.277	0.232	0.331	

Bootstrapping comparisons of means were carried out with 25,000 iterations and two-tailed probabilities.
* Significant at the $p < .05$ level, ** Significant at the $p < .1$ level

Table 4. Comparison of Spent Point Lengths

Hafting Method	Point Number	Original Length (cm)	Base to Break (cm)	% of point left
intermediate	1	2.15	1.7	0.79
intermediate	2	2.32	0.91	0.39
intermediate	4	2.42	0.72	0.30
intermediate	5	2.24	0	0.00
intermediate	8	2.13	1.37	0.64
intermediate	10	2.62	2.51	0.96
intermediate	11	2.08	1.45	0.70
intermediate	13	2.45	2.16	0.88
intermediate	14	2.33	1.94	0.83
intermediate	15	2.08	0.97	0.47
intermediate	16	2.26	1.66	0.73
intermediate	17	2.07	2.01	0.97
intermediate	18	2.3	2.11	0.92
intermediate	19	2.41	2.05	0.85
intermediate	20	2.31	2.19	0.95
to the tip	21	2.47	2.33	0.94
to the tip	22	2.32	1.77	0.76
to the tip	23	2.48	0.99	0.40
to the tip	25	2.31	1.44	0.62
to the tip	26	2.11	1.21	0.57
to the tip	27	2.46	1	0.41
to the tip	28	2.58	0.97	0.38
to the tip	29	2.27	2.13	0.94
to the tip	30	2.39	2.16	0.90
to the tip	32	2.36	1.65	0.70
to the tip	34	2.21	1.7	0.77
to the tip	36	2.37	2.12	0.89
to the tip	37	2.43	2.26	0.93
to the tip	38	2.16	1.77	0.82
to the tip	40	2.39	2.24	0.94
sinew	45	2.56	2.33	0.91
sinew	46	2.03	0.69	0.34
sinew	47	2.06	1.61	0.78
sinew	48	2.17	1.75	0.81
sinew	49	2.28	1.9	0.83
sinew	51	2.5	2.12	0.85

sinew	52	2.5	1.9	0.76
sinew	54	2.59	1.28	0.49
sinew	55	2.15	1.89	0.88
sinew	56	2.48	1.04	0.42
sinew	57	2.5	1	0.40
sinew	58	2.48	0.72	0.29
sinew	59	2.33	2.12	0.91
sinew	60	2.18	1.65	0.76
sinew	31	2.52	1	0.40